



US ARMY CORPS
OF ENGINEERS
New England District

Contract No. DACW33-01-D-0004

Delivery Order No. 02

November 2003

Final Report

PROFILE IMAGING OF AREA E AND AREA W, JULY 2003

**RHODE ISLAND REGION LONG-TERM DREDGED
MATERIAL DISPOSAL SITE EVALUATION PROJECT**

FINAL

Sediment Profile Imaging of Area E and Area W, July 2003

**Rhode Island Region
Long-Term Dredged Material Disposal Site Evaluation Project**

**Contract Number DACW33-01-D-0004
Delivery Order No. 02**

to

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November 13, 2003

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1.0 INTRODUCTION

There are many harbors, channels, and navigation-dependant facilities in Rhode Island and southeastern Massachusetts that must undergo periodic maintenance dredging to ensure safe navigation. Some harbors occasionally must be deepened beyond historical depths to meet changing economic and safety needs. The lack of a long-term dependable ocean disposal site has and will affect dredging activities in the region. EPA and the Corps are evaluating the designation of a long-term disposal site in the Rhode Island Region under section 102(c) of the Marine Protection Research and Sanctuaries Act (MPRSA) in a forthcoming EIS.

This report describes part of the environmental data collected in July 2003 to describe Alternative Areas W and E in Rhode Island Sound (Figure 1). Site characterization efforts at the Areas W and E are designed to fulfill the baseline monitoring requirements defined in the MPRSA regulations at Part 228.13. The sampling program also obtains information describing a contiguous area around each site, which will be used to evaluate areas for long-term monitoring.

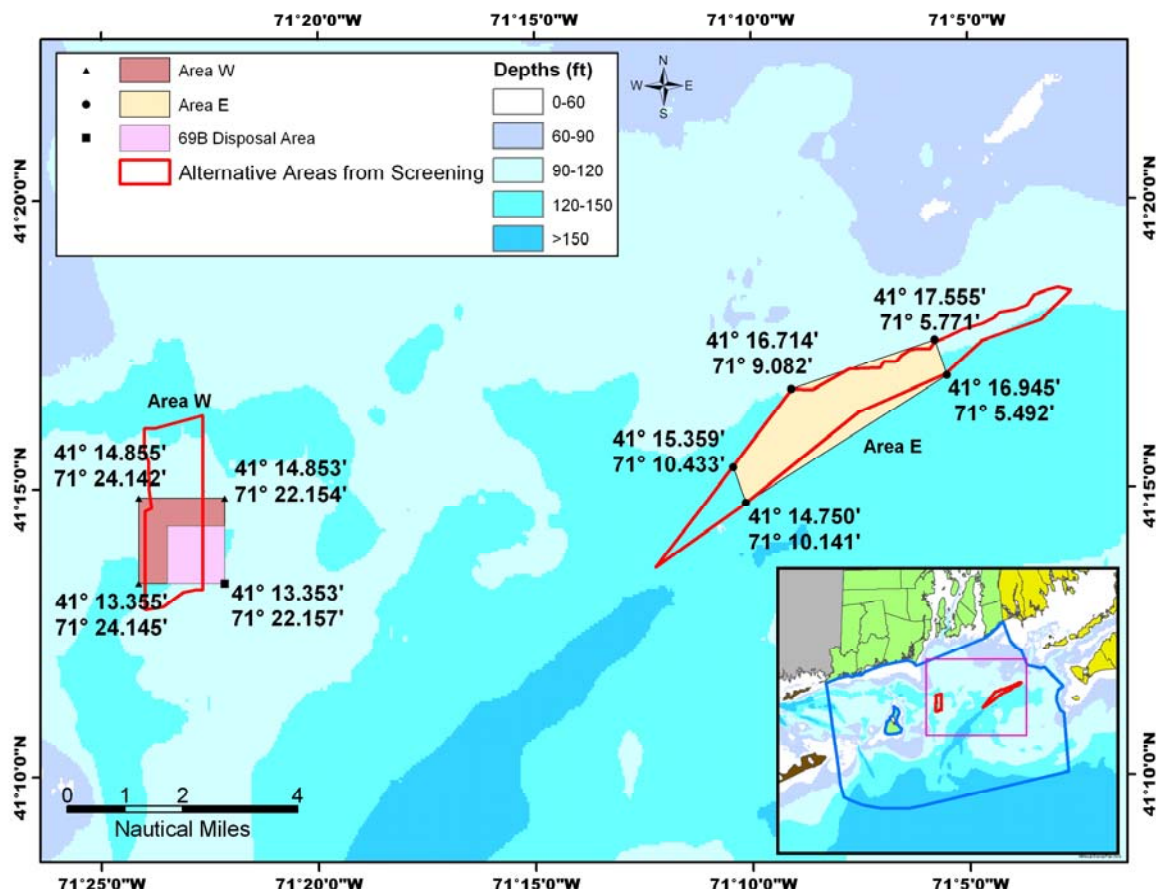


Figure 1. Location of Alternative Areas E and W in Rhode Island Sound.

To characterize current condition of benthic habitats in the Alternative Areas W and E, a sediment profile image (SPI) survey was conducted in July 2003. The SPI data were also used to determine the locations of the benthic grab stations. Rhoads and Cande (1971) developed sediment profiling as a means of obtaining *in situ* data on benthic habitats. The technology of remote ecological monitoring of the sea floor (REMOTS) or sediment profile imaging (SPI) has allowed for the development of a better understanding of the complexity of sediment dynamics, from biological and physical viewpoints (for examples see Rhoads and Germano 1986, Diaz and Schaffner 1988, Valente *et al.* 1992, Bonsdorff *et al.* 1996, Nilsson and Rosenberg 2000, and Rosenberg *et al.* 2001). The best example of this is the regional long-term monitoring conducted by the Massachusetts Water Resources Authority (MWRA), recently summarized by Werme and Hunt (2001). In addition, SPI provides ground-truth data for acoustic methods such as multibeam and side scan sonar.

2.0 MATERIALS AND METHODS

2.1 Sediment Profile Imaging

Sediment profile images were collected by using a sediment profile camera system developed and provided by Dr. Robert J. Diaz. The Diaz Sediment Profile Imaging System (SPI) is comprised of a 5.2 megapixel digital camera and strobe in a stainless steel housing and a 45° angle prism with a 16.5 by 23 cm Plexiglas face plate. The camera and prism are attached to a sturdy aluminum box frame equipped with a hydraulic arm to slowly lower the prism and camera into the sediment. Images were stored on a 1 gigabyte IBM microdrive. More detail on sediment profile camera operation can be found in Rhoads and Cande (1971).

2.2 Field Methods

On 26 July 2003, SPI images were collected at 57 of 60 proposed stations in Area E (Figure 2). Deteriorating weather precluded sampling the last three stations. On 28 July 2003, SPI images were collected at 20 of 20 proposed stations in Area W (Figure 3). At each station a digital sediment profile camera was deployed at least two times. Camera operation was monitored through a video feed to the surface vessel with preliminary evaluation of substrate and benthic conditions done in real-time. The camera was triggered from the surface twice, once approximately 1-sec after bottom contact and again after the prism stopped penetrating the sediment. While still in the field, images were transferred from the microdrive to a computer and then to a CD for long-term storage.

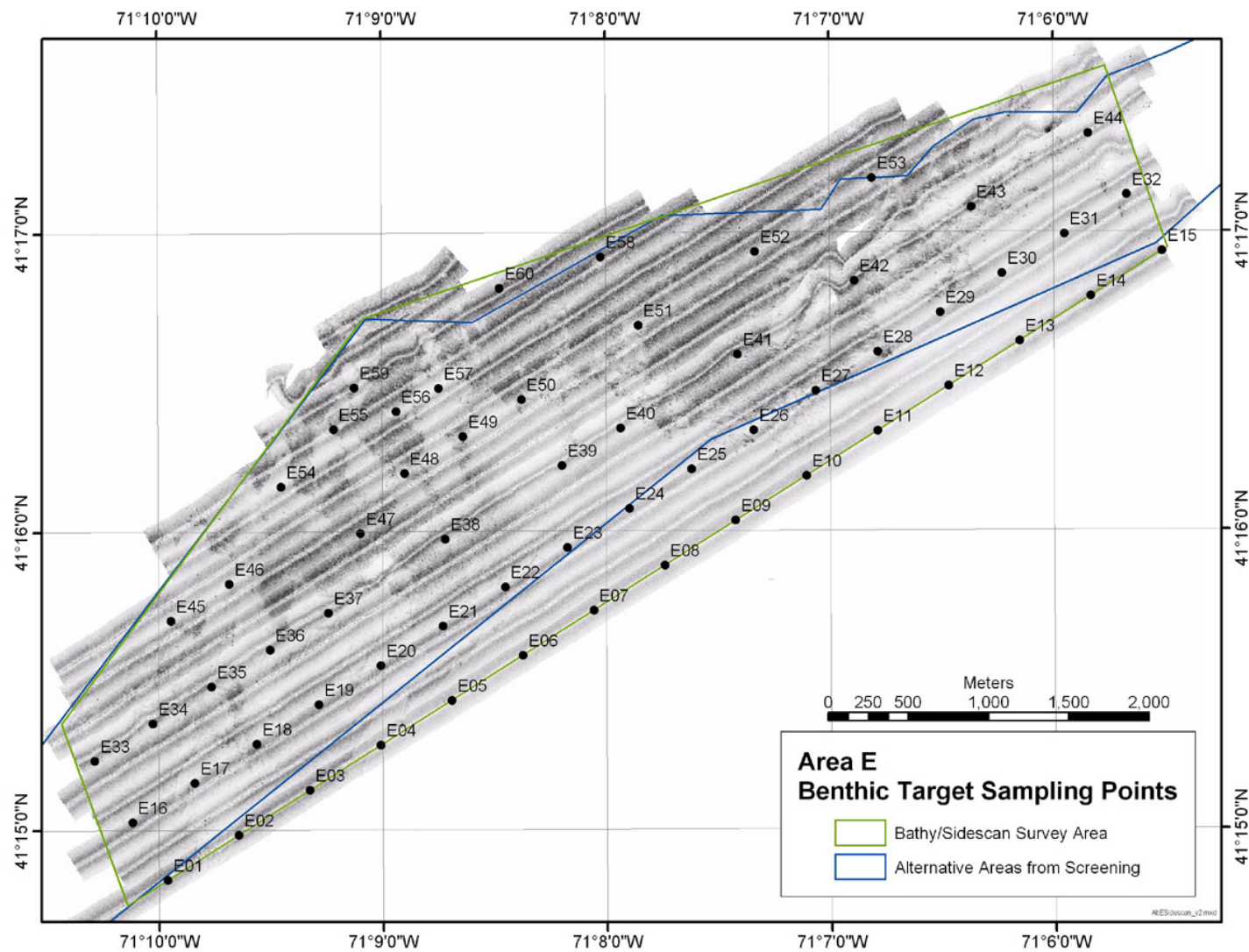


Figure 2. Location of Stations in Area E Overlaid on Side Scan Mosaic.

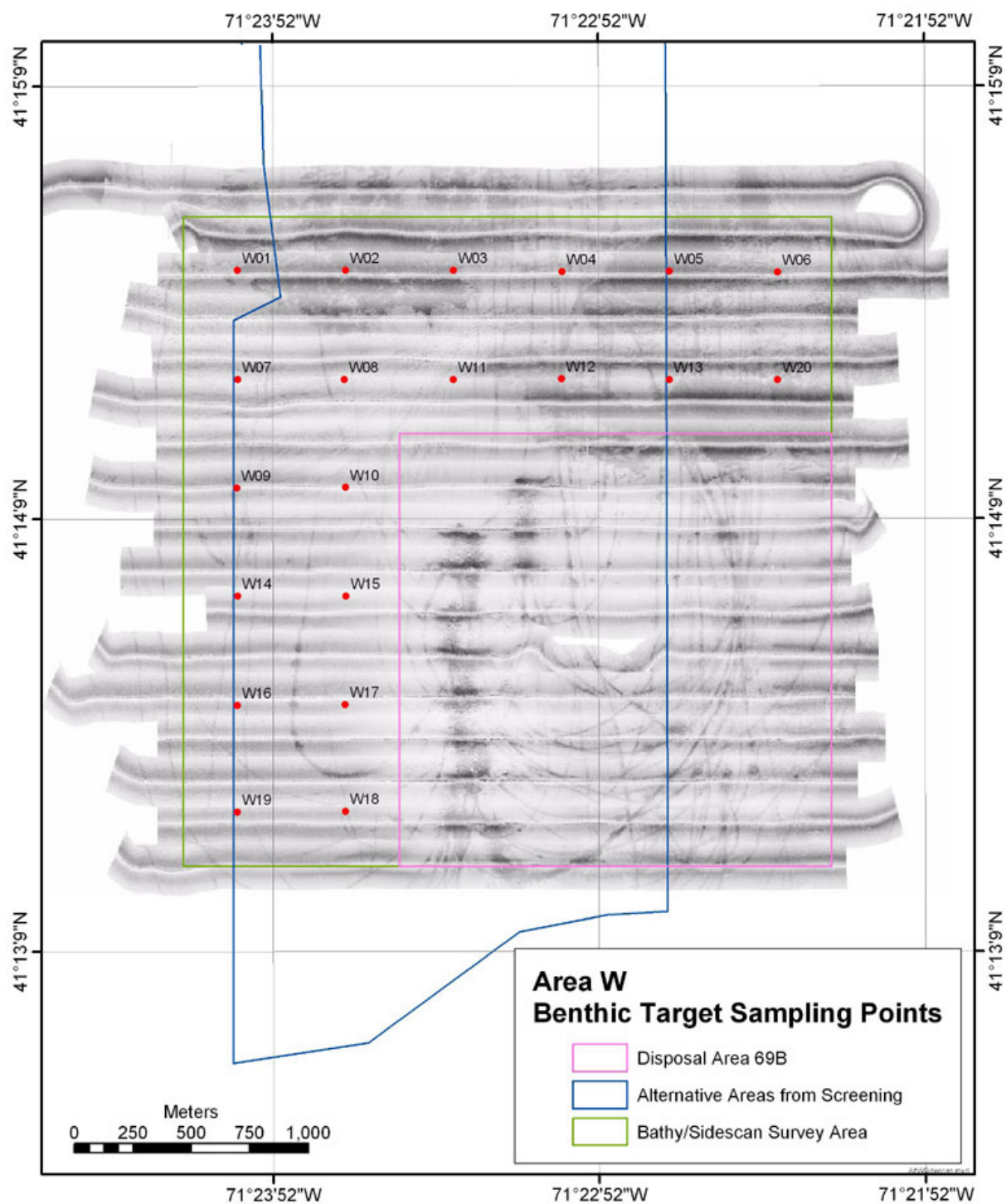


Figure 3. Location of Stations in Area W Overlaid on Side Scan Mosaic.

2.3 Image Analysis

Steps in the computer analysis of each image were standardized and followed the basic procedures in Viles and Diaz (1991). Data from each image were sequentially saved to a spread sheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988) and Rhoads and Germano (1986). A summary of major parameters measured follows.

2.3.1 Prism Penetration

This parameter provided a geotechnical estimate of sediment compaction with the profile camera prism acting as a dead weight penetrometer. The further the prism entered into the sediment the softer the sediments, and likely the higher the water content. Penetration was measured as the distance the sediment moved up the 23-cm length of the faceplate. The weight on the camera was kept constant at 125 lbs (56.7 kg) to allow comparison among stations.

2.3.2 Surface Relief

Surface relief or boundary roughness was measured as the difference between the maximum and minimum distance the prism penetrated. This parameter also estimated small-scale bed roughness, on the order of the prism faceplate width (16.5 cm), which is an important parameter for predicting sediment transport and in determining processes that dominate surface sediments. The origin of bed roughness can be determined from visual analysis of the images. In physically dominated habitats, features such as bedforms and sediment granularity cause bed roughness. In biologically dominated habitats, bed roughness is a result of biogenic activity such as tube structures, defecation mounds, feeding pits, or epifaunal organisms such as hydroids.

2.3.3 Apparent Color Redox Potential Discontinuity (RPD) Layer

This parameter is an important estimator of benthic habitat conditions, which relates directly to the quality of the habitat (Rhoads and Germano 1986, Diaz and Schaffner 1988, Nilsson and Rosenberg 2000). RPD provides an estimate of the depth to which sediments appear to be oxidized. The term apparent is used in describing this parameter because no actual measurement was made of the redox potential. It is assumed that given the complexities of iron and sulfate reduction-oxidation chemistry the reddish-brown sediment color tones (Diaz and Schaffner 1988, Rosenberg *et al.* 2001) indicate sediments are in an oxidative geochemical state, or at least are not intensely reducing. This is in accordance with the classical concept of RPD layer depth, which associates it with sediment color (Fenchel 1969, Vismann 1991). The apparent color RPD has been very useful in assessing the quality of a habitat for epifauna and infauna from both physical and biological points of view. Rhoads and Germano (1986), Revelas *et al.* (1987), Day *et al.* (1988), Diaz and Schaffner (1988), Valente *et al.* (1992), Bonsdorff *et al.* (1996), Nilsson and Rosenberg (2000), and Rosenberg *et al.* (2001) all found the depth of the RPD layer from sediment profile images to be directly

correlated to the quality of the benthic habitat. These authors all found that deeper RPD layers were always associated with higher benthic habitat quality.

2.3.4 Sediment Grain Size

Grain size is an important parameter for determining the nature of the physical forces acting on a habitat and is a major factor in describing benthic community composition (Rhoads 1974). The sediment type descriptors used for image analysis follow the Wentworth classification as described in Folk (1974) and represent the major modal class for each image. For muddy to fine-sandy sediments grain-size was determined by comparison of collected images with a set of standard images for which mean grain size had been determined in the laboratory. For sediments larger than fine-sand, individual grains were measured. The following is provided as a means of comparing Phi scale sizes corresponding to sediment descriptors derived from SPI images:

Phi Scale	Upper Limit Size (mm)	Grains per cm of image	SPI Descriptor	Sediment Size Class & Subclass
-6 to -8	256.0	<<1	CB	Cobble
-2 to -6	64.0	<1	PB	Pebble
-1 to -2	4.0	2.5	GR	Gravel
0 to -1	2.0	5	VCS	Very-coarse-sand
1 to 0	1.0	5	CS	Coarse-sand
2 to 1	0.5	20	MS	Medium-sand
3 to 2	0.25	40	FS	Fine-sand
4 to 3	0.12	80	VFS	Very-fine-sand
5 to 4	0.06	160	FSSI	Fine-sandy-silt
5.5 to 4.5	0.06	160	FSSICL	Fine-sandy-silt-clay
6 to 5	0.0039	>320	SIFS	Silty -fine-sand
8 to 6	<0.0039	>320	SICL	Silty-clay
>8 to 7	<0.0039	>320	CLSI	Clayey-silt
>8	<0.0005	>2560	CL	Clay

2.3.5 Surface and Subsurface Features

Included are a wide variety of physical (such as bedform) and biological features (such as biogenic mounds, shell, or tubes). Each contributes information on the type of habitat and its ability to support benthic organisms. The presence of certain surface features is indicative of the overall nature of a habitat. For example, bedforms are always associated with physically dominated habitats, whereas the presence of worm tubes or feeding pits would be indicative of a more biologically accommodated habitat (Rhoads and Germano 1986, Diaz and Schaffner 1988). Surface features were visually evaluated from each image and compiled by type and frequency of occurrence.

Subsurface features include a wide variety of features (such as infuunal organisms, burrows, water filled voids, gas voids, or sediment layering) that reveal detail about physical and

biological processes acting on the bottom. For example, habitats with grain-size layers or homogeneous color layers indicative of major resuspension/deposition events are generally dominated by physical processes while habitats with burrows, infaunal feeding voids, and/or visible infaunal organisms are generally dominated by biological processes (Rhoads and Germano 1986, Diaz and Schaffner 1988, Valente *et al.* 1992, Nilsson and Rosenberg 2000). Subsurface features were visually evaluated from each image and compiled by type and frequency of occurrence.

2.3.6 Successional Stage

Sediment profile data have also been used to estimate benthic successional stage (Rhoads and Germano 1986). Characteristics associated with pioneering or colonizing (Stage I) assemblages (in the sense of Odum 1969), such as dense aggregations of small polychaete tubes at the surface and shallow apparent RPD layers, can be seen in sediment profile images. Advanced or equilibrium (Stage III) assemblages also have characteristics that are seen in profile images, such as deep apparent RPD layers and subsurface feeding voids. Stage II is intermediate to Stages I and III, and has characteristics of both (Rhoads and Germano 1986). A group of SPI parameters is evaluated to determine successional stage; with the following being the generalized associations (- = not associated with, + = associated with, ++ = moderately associated with, +++ = strongly associated with):

Parameter	Successional Stage		
	I	II	III
RPD layer depth:			
Average RPD (cm)	<1	1-3	>2
Max depth RPD (cm)	<2	>2	>4
Surface Features:			
Small Tubes	+++	++	+
Large Tubes	-	++	+++
Epifauna	+	++	++
Subsurface Features:			
Burrows	-	++	+++
Feeding Voids	-	+	+++
Small Infauna	+++	++	+
Large Infauna	-	+	++

2.3.7 Organism Sediment Index

Rhoads and Germano (1986) developed the multi-parameter organism-sediment index (OSI), from data provided by the sediment profile images, to characterize benthic habitat quality. The OSI defines quality of benthic habitats by evaluating the depth of the apparent RPD, successional stage of macrofaunal organisms, the presence of gas bubbles in the sediment (an indication of high rates of methanogenesis that are associated with high carbon inputs to the sediments), and visual signs of the presence of low dissolved oxygen conditions (sulfide covered tubes, anaerobic sediment at the interface, bacterial mats) at the sediment-water interface. The

following parameter ranges and scores are used in the calculation of the OSI (taken from Rhoads and Germano 1986):

Depth of the apparent color RPD:		Estimated successional stage:	
0 cm	0	Azoic	−4
>0-0.75	1	I	1
0.76-1.50	2	I-II	2
1.51-2.25	3	II	3
2.26-3.00	4	II-III	4
3.01-3.75	5	III	5
>3.75	6	I on III	5
		II on III	5
Other:			
Methane or gas voids present			−2
Appearance of low DO			−4

The OSI ranges from −10, poorest quality habitats, to +11, highest quality habitats. The OSI has been used to map disturbance gradients (Valente *et al.* 1992) and to follow ecosystem recovery after disturbance abatement (Rhoads and Germano 1986, Day *et al.* 1988, Revelas *et al.* 1987). For estuarine and coastal bay benthic habitats in the northeastern United States OSI values >6 indicate good habitat conditions and are generally associated with bottoms that are not heavily influenced by stress, either physical or anthropogenic. The formulation of the OSI and contribution of each component are scaled to reflect the increasing importance of bioturbation, sediment mixing mediated by organisms, and other biogenic activity, such as structure building, in defining good benthic habitat quality. The scaling used in the calculation of the OSI was developed for estuarine and coastal bay benthic habitats and has not been calibrated (re-scaled) for assessing open coastal and oceanic benthic habitats.

2.3.8 Statistics

Analysis of variance was used to test for differences between and within areas for quantitative parameters. Normality was checked with the Shapiro-Wilk test and homogeneity of variance with Bartlett's test (Zar 1999).

3.0 RESULTS AND DISCUSSION

Sediment profile image (SPI) data for Alternative Areas E and W are summarized in Tables 1 and 2, respectively. All SPI replicate data are in CD-ROM Appendices. Appendix I contains the data and Appendix II the images. Plates 1 to 5 contain all images from Area E and Plates 6 and 7 Area W images. For size comparison of various features the width of all images in the Plates and in Appendix II is 16.5 cm. All images have been processed to highlight the apparent color RPD layer and other sedimentary features. See Figures 2 and 3 for the location of all stations. Area E stations were designated E01 through E60 and Area W stations W01 through W20. Throughout the text example stations are given in parentheses. To view images high resolution copies of images cited in the text consult the CD-ROM Appendix or for low resolution images see the Plates.

3.1 Sediments and Processes

Sediments at Alternative Areas E and W ranged from cobble to fine-sand with some silt. Coarsest grained sediments tended to be more heterogeneous and were mixtures of sands, gravel, pebble, and cobble. Modal grain size at 40% (23 of 57) of Area E stations and 35% (7 of 20) of Area W stations was coarse- sand (1 to 0 Phi or coarser) (Tables 1 and 2). The remaining stations had finer sediments, primarily fine-sand with some silt (4.5 to 3.5 Phi). Area E had a higher proportion of homogeneous fine-grained stations, only fine sand and silt, than Area W, 37% versus 10% respectively.

The spatial distribution of sediment types within Areas E and W closely matched the reflectance from the side scan mosaic (Figures 4 and 5). The highest reflectance occurred along the northern side of Area E where the coarsest sediments (gravel, pebble and cobble) were observed. The southern side of Area E was primarily fine-sand with some silt. Near the center of Area E finer sediments (fine sand with some silt) divided the coarser-sediment stations into patches. Toward the southwest, sediment became sandy. In Area W, the highest reflectance was on the northern side of the area where the coarsest sediment (gravel, pebble, cobble) occurred. Finer sediments (fine sand with silt) occurred on the western side of Area W.

Within Area E, the processes structuring surface sediments were predominantly physical, with 61% of the station's surface sediments dominated by physical structures such as bedforms and large sediment grains (for example E19 and E42) (Table 1). At the other 39% of stations, biological processes structured surface sediments, with biogenic structures such as feeding mounds and tubes dominating the sediment surface (E23 or E39). However, even at the physically dominated coarse-sand stations there was evidence of biogenic activity in the form of fine, silty-sediment tubes (E03).

Table 1. Summary of sediment profile image data for Alternative Area E, August 2003. Data for quantitative parameters (Penetration, Surface Relief, RPD, Layers, Stick Amphipods, Infauna, Burrows, Oxidic Voids, and OSI) are means, either cm or number per image. Qualitative parameter (Grain-Size, Surface Process, Bedforms, Tubes, Successional Stage) are the cumulative sum for the two replicate images.

Stat	Min	Max	Grain-Size Modal	Pene- tration (cm)	Surface Relief (cm)	Surface Process	RPD ¹ (cm)	Bed- form	Layer (cm)	Amphipod Tubes	Worm Tubes	Stick Amphi.	Infauna	Burrow	Oxidic Voids	SS	OSI
E01	MS	PB	CSMS	4.1	1.9	PHY	>4.1	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.5
E02	MS	CS	MS	3.3	1.3	PHY	>3.3	X		SOME	MANY	0.0	0.0	0.0	0.0	I-II	7.0
E03	MS	GR	CSMSGR	3.5	1.0	PHY	>3.5	X		NONE	MANY	0.0	0.0	0.0	0.0	I-II	7.0
E04	SI	FS	FSSI	7.9	0.8	BIO	4.2			SOME	MANY	1.5	0.0	7.5	0.0	II-III	9.5
E05	SI	FS	FSSI	7.5	1.1	BIO	3.3			SOME	MANY	3.5	0.5	7.0	2.0	III	10.0
E06	SI	FS	FSSI	6.9	0.8	BIO	4.0			NONE	MANY	0.5	0.5	9.0	0.0	II-III	10.0
E07	SI	FS	FSSI	6.6	0.8	BIO	4.4			SOME	MANY	4.0	0.5	5.5	0.5	II-III	10.0
E08	SI	FS	FSSI	8.2	0.9	BIO	4.2			NONE	MANY	3.0	1.5	6.0	2.0	III	11.0
E09	SI	FS	FSSI	7.8	1.3	BIO	3.2			FEW	MANY	2.0	1.0	6.0	1.5	III	9.5
E10	SI	FS	FSSI	7.7	1.4	BIO	3.5			FEW	MANY	2.5	0.5	5.0	1.0	II-III	9.5
E11	SI	FS	FSSI	10.9	0.5	BIO	3.0			FEW	MANY	3.5	4.0	9.0	2.0	II-III	8.5
E12	SI	FS	FSSI	10.6	1.0	BIO	2.2			NONE	SOME	1.5	1.5	6.5	0.5	II-III	7.5
E13	SI	FS	FSSI	10.2	1.6	BIO	2.3			SOME	SOME	0.0	0.0	3.5	0.5	II-III	8.0
E14	SI	FS	FSSI	9.7	1.1	BIO	3.2			FEW	MANY	8.5	1.5	5.5	0.0	II-III	8.5
E15	SI	FS	FSSI	8.1	0.6	BIO	4.3			SOME	MANY	0.5	1.0	6.0	2.0	III	11.0
E16	MS	GR	CSMS	4.3	2.2	PHY	>4.3	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.0
E17	SI	GR	FSMS	4.5	1.1	PHY	3.9	X		FEW	SOME	0.0	0.5	2.5	0.5	I-II	7.5
E18	SI	PB	CSMSGRPB	3.4	0.9	PHY	>3.4	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.0
E19	MS	VCS	MSCS	4.9	2.4	PHY	>4.9	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	8.0
E20	SI	MS	MSFS	4.1	0.8	PHY	>4.1	X		FEW	SOME	0.0	0.0	0.0	0.0	I-II	8.0
E21	MS	GR	MSFSCS	5.9	1.8	PHY	>5.9	X		SOME	FEW	0.0	0.0	0.0	0.0	I-II	8.0
E22	MS	PB	MSFS	3.3	0.2	PHY	>3.3	X		FEW	SOME	0.0	0.0	0.0	0.0	I-II	7.0
E23	SI	FS	FSSI	8.9	1.1	BIO	6.9			NONE	SOME	2.0	1.0	4.5	2.0	II-III	10.0
E24	SI	FS	FSSI	9.6	1.1	BIO	4.0			NONE	MANY	2.0	1.5	6.5	3.0	III	11.0
E25	SI	FS	FSSI	9.6	0.6	BIO	4.7			FEW	MANY	1.0	1.0	8.0	1.5	II-III	9.5
E26	SI	FS	FS	9.8	1.1	BIO	7.9			FEW	SOME	0.5	1.0	3.0	4.5	III	11.0
E27	SI	PB	SHGRPB	0.3	1.1	PHY	IND				NONE	SOME	0.0	.	.	I-II	.
E28	SI	CB	PBCB	0.0	.	PHY	IND				NONE	FEW	0.0	.	.	I-II	.
E29	SI	FS	FSSI	7.3	1.3	BIO	4.2			FEW	MANY	1.5	1.0	9.0	1.0	II-III	10.0

¹ Only measured RPDs or values > the penetration were used in the calculation of the mean.

Table 1. (Continued)

Stat	Min	Grain-Size		Pene- tration (cm)	Surface Relief (cm)	Surface Process	RPD ¹ (cm)	Bed- form	Layer (cm)	Amphipod Tubes	Worm Tubes	Stick Amphi.	Infauna	Burrow	Oxic Voids	SS	OSI
E30	SI	FS	FSSI	9.0	0.9	BIO	2.6			FEW	SOME	3.5	1.5	5.0	1.5	III	8.5
E31	SI	FS	FSSI	8.2	0.3	BIO	4.0			FEW	MANY	0.0	0.5	6.0	3.0	III	10.5
E32	SI	GR	FS	5.4	2.3	PHY	3.3			NONE	MANY	3.5	0.0	3.5	0.5	II-III	8.5
E33	MS	GR	CSMS	3.8	2.1	PHY	>3.8	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.5
E34	FS	PB	MSFSGRPB	3.7	1.2	PHY	>3.7	X		NONE	SOME	0.5	0.0	0.0	0.0	I-II	7.5
E35	SI	GR	FSMS	5.8	1.2	PHY	>5.8	X		NONE	MANY	1.5	2.0	1.5	1.0	II-III	10.0
E36	SI	VCS	FSMS	3.4	0.9	PHY	>3.4	X		FEW	SOME	0.0	0.0	0.0	0.0	I-II	7.0
E37	FS	CS	MSFS	3.8	1.0	PHY	>3.8	X		SOME	SOME	0.0	0.0	0.0	0.0	I-II	7.5
E38	SI	GR	PBFSSI	1.0	1.2	PHY	>1.2			NONE	MANY	2.0	0.0	0.0	0.0	I-II	4.0
E39	SI	FS	FSSI	8.6	0.8	BIO	3.9			SOME	MANY	4.5	1.0	6.0	2.0	II-III	10.0
E40	SI	FS	FSSI	8.9	1.4	BIO	6.0			FEW	MANY	3.5	1.0	6.5	1.0	III	10.5
E41	SI	PB	PBFSSI	2.0	1.4	PHY	2.1			NONE	SOME	1.0	0.0	0.0	1.0	I-II	5.0
E42	SI	CB	PBFSSI	0.8	3.3	PHY	>1.6			NONE	SOME	0.5	0.0	0.0	0.0	I-II	5.0
E43	SI	CB	CBPB	0.0	.	PHY	IND				NONE	NONE	0.0	.	.	I-II	.
E44	VFS	PB	FS	7.4	1.9	PHY	5.4	X		FEW	MANY	0.0	1.0	2.5	0.0	I-II	8.0
E45	SI	GR	MSFS	3.5	0.9	PHY	>3.5	X		NONE	SOME	0.0	0.5	0.0	0.0	I-II	7.0
E46	SI	GR	FSSIGR	4.4	1.3	PHY	5.2	X		NONE	SOME	1.0	0.0	2.0	0.5	I-II	9.0
E47	SI	CB	CBPBGRMSCS	1.1	1.8	PHY	>2.2			NONE	SOME	0.0	0.0	0.0	0.0	I-II	5.0
E48	SI	PB	PBGRFSSI	0.6	1.1	PHY	IND				NONE	SOME	0.0	.	.	I-II	.
E49	SI	CB	CBPBGR	0.0	.	PHY	IND				NONE	MANY	0.0	.	.	I-II	.
E50	FS	CB	FSMSGRCB	2.5	0.9	PHY	2.9			NONE	SOME	0.0	0.0	3.0	0.0	I-II	6.0
E51	SI	FS	FS	9.2	0.8	PHY	6.5			NONE	SOME	0.0	1.5	3.0	3.0	II-III	10.0
E52	SI	PB	PBFSSI	1.7	1.4	PHY	2.0			NONE	SOME	0.0	0.0	0.0	3.0	I-II	5.0
E53	SI	PB	MSFSGRPB	0.2	0.9	PHY	IND				NONE	SOME	0.0	.	.	I-II	.
E54	SI	FS	FSSI	9.1	1.5	BIO	4.6			NONE	SOME	3.5	3.0	5.0	2.0	III	10.5
E58	SI	CB	CBPBGR	0.0	.	PHY	IND				NONE	SOME	0.0	.	.	I-II	.
E59	SI	FS	FS	7.6	1.0	PHY	>7.6	X		NONE	SOME	0.0	1.0	0.5	0.0	I-II	8.0
E60	SI	CB	CBPB	0.0	.	PHY	IND				NONE	SOME	0.0	.	.	I-II	.

¹ Only measured RPDs or values > the penetration were used in the calculation of the mean.

Table 2. Summary of sediment profile image data for Alternative Area W, August 2003. Data for quantitative parameters (Penetration, Surface Relief, RPD, Layers, Stick Amphipods, Infauna, Burrows, Oxidic Voids, and OSI) are means, either cm or number per image. Qualitative parameter (Grain-Size, Surface Process, Bedforms, Tubes, Successional Stage) are the cumulative sum for the two replicate images.

Stat	Min	Max	Grain-Size Modal	Pene- tration (cm)	Surface Relief (cm)	Surface Process	RPD ¹ (cm)	Bed- form	Layer (cm)	Amphipod Tubes	Worm Tubes	Stick Amphi.	Infauna	Burrow	Oxidic Voids	SS	OSI
W01	SI	PB	FSSI	5.7	1.3	PHY	>5.7	X		NONE	MANY	0.0	0.0	0.0	0.5	I-II	8.0
W02	SI	CB	PBGRFSSI	1.3	1.9	PHY	>1.7			NONE	SOME	0.0	0.0	0.0	0.0	I-II	5.0
W03	SI	CB	CBPBGRFSSI	0.8	1.0	PHY	>1.3			NONE	MANY	0.0	0.0	0.0	0.0	I-II	4.0
W04	SI	PB	FS	4.0	1.2	PHY	>4.0			NONE	MANY	0.0	0.5	0.0	1.5	I-II	7.5
W05	SI	PB	PBGRFSSI	2.3	1.3	PHY	>3.6			NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.0
W06	SI	PB	MSFSGRPB	1.5	0.4	PHY	>3.0	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	6.0
W07	SI	PB	FS	3.5	2.3	PHY	>3.5	X		NONE	MANY	0.0	0.0	1.0	1.0	I-II	7.0
W08	SI	GR	FS	4.2	1.3	PHY	>4.2	X		NONE	SOME	0.0	0.0	2.5	1.5	I-II	7.5
W09	SI	MS	FSMS	3.3	1.1	PHY	>3.3	X		NONE	MANY	0.5	0.0	0.0	0.0	I-II	7.0
W10	SI	FS	FS	5.3	1.1	PHY	>5.3	X	0.1	SOME	SOME	0.0	0.0	1.5	1.0	I-II	8.0
W11	SI	MS	FS	5.9	1.0	PHY	>5.9	X		NONE	MANY	0.0	0.5	0.5	0.5	I-II	8.0
W12	SI	PB	PBGR	0.2	1.0	PHY	IND	.		NONE	NONE	SOME	0.0	.	.	I-II	.
W13	SI	CB	CSMSPB	3.2	3.1	PHY	>3.2	X		NONE	SOME	0.0	0.0	0.0	0.0	I-II	6.5
W14	SI	FS	FS	6.9	0.5	PHY	>6.9			NONE	SOME	0.0	2.0	2.5	1.5	I-II	8.0
W15	SI	FS	FSSI	7.6	1.4	PHY	1.1		1.7	NONE	FEW	0.0	0.0	0.0	2.0	I-II	4.0
W16	SI	MS	FSMS	7.1	0.4	PHY	>7.1		0.1	FEW	FEW	0.0	0.0	0.0	1.5	II-III	10.0
W17	SI	FS	FSSI	6.3	1.5	PHY	>6.3		1.1	NONE	FEW	0.0	0.0	0.0	2.0	II-III	10.0
W18	SI	GR	FSSI	6.0	1.1	PHY	>6.0		0.1	NONE	FEW	0.0	0.5	0.0	1.5	I-II	8.0
W19	SI	VCS	FSMS	6.5	1.3	PHY	>6.5			FEW	SOME	0.0	0.5	2.0	1.0	I-II	8.0
W20	SI	CB	CBPBGRFSMS	1.7	1.8	PHY	>3.3			NONE	SOME	0.0	0.0	0.0	0.0	I-II	7.0

¹ Only measured RPDs or values > the penetration were used in the calculation of the mean.

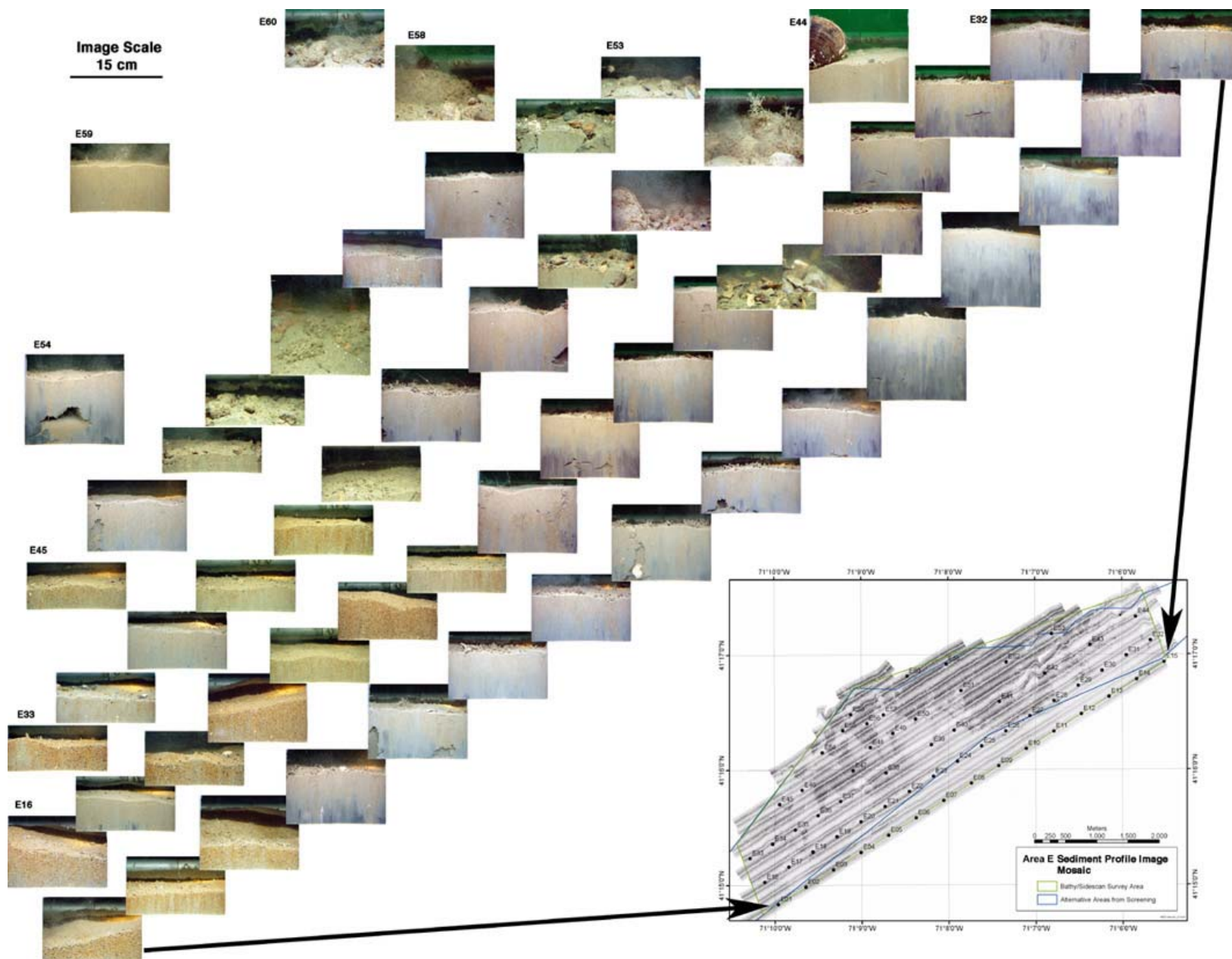


Figure 4. Area E Mosaic with SPI Stations and Images Aligned with Side Scan Mosaic.

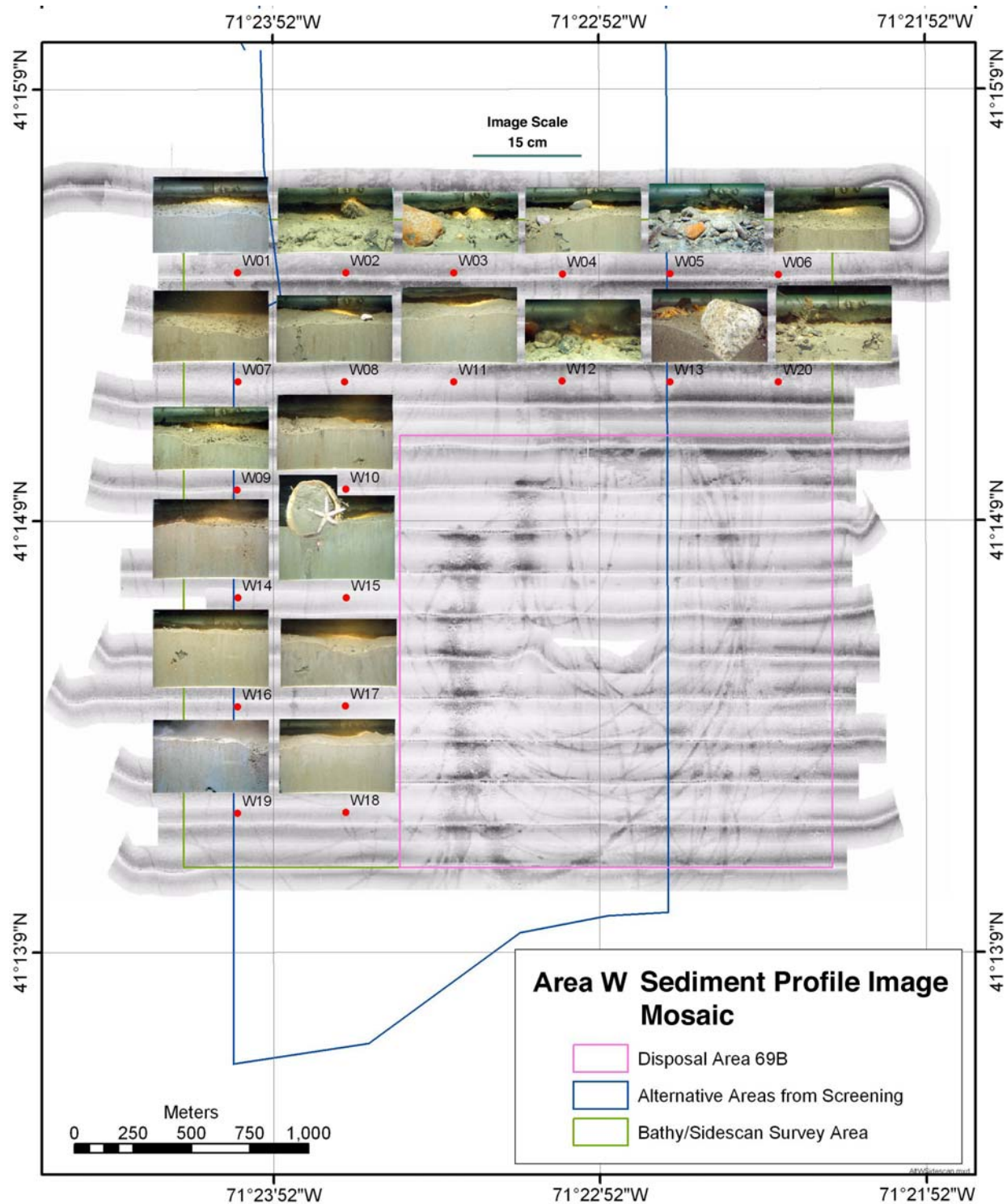


Figure 5. Area W Mosaic with SPI Stations and Images Aligned with Side Scan Mosaic.

Physical processes were more prominent in structuring surface sediments at Area W as all 20 stations appeared to be physically dominated (Table 2). At nine of the stations there was evidence that physical and biological processes structured surface sediments, with biogenic structures in the form of tubes being common (W06 or W09). There did not appear to be any spatial pattern within Area W relative to dominant surface processes that was not also associated with sediment distribution (Figure 5).

Sediment grain-size layering was observed in Area W at two stations (W15 and W17). These layers were at the sediment-water-interface and appeared to be finer than the deeper sediments. The layer was 1.7 cm thick at W15 and 1.1 cm thick at W17 (Table 2, Figure 5). The layer at W15 was more pronounced. There were also traces of sediment layering at stations W16 and W18. All four of these stations were located along the southwestern side of Area W adjacent to high reflectance lines in the side scan mosaic that appeared to be some type of disturbance on the seafloor (Figures 3 and 5).

3.2 Bed Roughness

Prism penetration reflected the heterogeneity of sediment texture at Areas E and W. Sediments coarser than gravel had little to no penetration and silty fine-sands had the deepest penetration. In Area E, the range of penetration was 0.0 cm at five cobble-pebble stations to >10.0 cm at three fine-sandy-silt stations (Table 1). In Area W, penetration ranged from 0.2 cm at W12 to 7.6 cm at W15 (Table 2).

Small-scale surface boundary roughness, estimated from surface relief, was about the same in Areas E and W (Tables 1 and 2) and averaged 1.2 cm and 1.3 cm, respectively. Within Area E, boundary roughness at stations where surface sediments were dominated by physical processes was significantly higher than at biologically dominated stations (ANOVA, $df = 1$, $p = 0.015$). For physically dominated stations, surface relief averaged 1.4 cm (SE = 0.10 cm), whereas relief averaged 1.0 cm (SE = 0.11 cm) at biologically dominated stations.

3.3 Apparent Color RPD Layer Depth

RPD layer depth is a measure of the depth to which sediment geochemical processes are primarily oxidative. Below the RPD layer geochemical processes are anaerobic or reducing. In porous sandy sediments (E21), deep RPD layers are primarily a function of pore water circulation driven by current or wave action that pumps oxygenated water into the sediments. In finer sediments, those with a significant silt and clay component (E08), physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech 1985). When the RPD layers in fine sediments are >1 cm, bioturbation by infaunal organisms (Rhoads 1974) or major resuspension/deposition events (Don Rhoads, personal communication) are responsible for oxygenating sediments. From the predominance of biogenic structures at the finer sediment stations in Area E, it appeared that biological processes regulated the depth of the RPD layer there (E24). There was no evidence in the images, such as homogeneous layered sediments, that the RPD layers at Area E stations were regulated by resuspension/deposition events. The most homogenous sediments were fine sands that occurred at Station E59 where the RPD layer depth

was greater than the 7.6-cm prism penetration depth (Table 1). At the 22 stations with measured RPD layers and biologically dominated surface sediments, the mean RPD layer depth was 4.1 cm (SE = 0.29 cm), which was not significantly different than the mean of 3.9 cm (SE = 0.58 cm) for the 8 physically dominated stations with RPD measurements.

Because of the coarse nature of sediments at many of the Area E stations, the RPD layer was deeper than prism penetration at 47% (27 of 57) of stations. The grand mean RPD layer depth at the 30 stations with measured RPD layers was 4.1 cm (SD = 1.42 cm) (Table 1). The shallowest RPD of 2.0 cm was observed at E52 and the deepest measured RPD layer of 7.9 cm at E26. At Area W, the only measured RPD layer was 1.1 cm at W15 (Table 2). The RPD layer at all other Area W stations was deeper than the prism penetration depth. These deeper-than-penetration RPD layers at Area W are an indication that physical processes can oxygenate sediments well below the sediment-water interface.

At Areas E and W, infaunal burrows convoluted the plane of the RPD layer and projected oxidized sediments deep below the sediment-water-interface. At E40 burrows extended oxic sediment to as deep as 9.4 cm below the sediment-water-interface (Plate 4). The degree of biogenic activity at Area E indicated the presence of well-developed populations of equilibrium successional stage organisms, which are associated with good benthic habitat conditions (Rhoads 1974, Pearson and Rosenberg 1978, Nilsson and Rosenberg 2000). Biogenic activity in benthic habitats in Area E was higher than in Area W.

Anaerobic sediments below the RPD layer at Area E and the one station at Area W with measured RPD did not appear to be intensely reducing or sulfidic (dark gray-blue in color), which is indicative of low organic carbon concentrations in the sediments. The darker color of reduced sediments underlying the oxidized lighter colored sediments is a function of organic carbon content and geochemistry with darker sediments tending to have higher organic content (Vismann 1991). There was no evidence of anaerobic voids or gas voids, which are the primary visual clues for organically enriched sediments.

3.4 Biogenic Activity

Equilibrium successional Stage III fauna appeared to be present at 44% (25 of 57) of stations in Area E (Table 1). Well-developed Stage III communities are characterized by high densities of large head-down deposit feeders such as maldanid polychaetes, which were likely responsible for most of the active feeding voids seen in many of the images. At E54, there appeared to be a worm extending down into an oxic void. Other Stage III fauna or indicators included large tube builders (E13), larger infaunal burrowers (E31), oxic feeding voids (E54), or large burrows (E08). Small worm tubes typically associated with pioneering successional Stage I communities were not abundant at any station, with most stations, for example E01 and W14, having <25 small tubes per image (Table 1). Intermediate Stage II fauna was most wide spread and occurred at 82% of Area E stations and all of Area W stations. Stage II fauna appeared to be *Ampelisca* spp. (E37) and surface feeding worms (W06).

Overall, Area W stations did not appear to be as successional advanced as Area E stations. Equilibrium Stage III fauna appeared to be present at only 10% (2 of 20) of Area W stations (W16 and W17). Intermediate Stage II fauna occurred at all Area W stations. Pioneering Stage I fauna were more abundant and present at 90% of Area W stations (Table 2).

In the soft unconsolidated sediments, the most widely distributed biogenic surface features were feeding pits and defecation mounds produced by the infauna. These structures occurred at all stations with sediments classified as biologically dominated (Tables 1 and 2). Larger tubes, >2 mm in diameter, occurred at 24 stations in Area E (for example E09 or E32) and at 2 stations in Area W (W13 and W15). On the coarser-grained sediments, hydroids, small tubes, and other epiphytes were attached to shells, pebbles, and cobbles, which enhanced physical habitat complexity. There did not appear to be any spatial pattern in the distribution of surface biogenic features.

Subsurface biogenic structures (oxic voids, burrows, and infaunal organisms) occurred at all biologically dominated and at 30% of the physically dominated stations in Area E, and also at 30% of the stations in Area W (Tables 1 and 2). Burrows and infaunal organisms were the most common subsurface biogenic structures in Areas E and W and were observed in sediments that were primarily fine sands (modal categories of FS, FSSI, and FSMS). The coarsest sediment type to have subsurface biogenic structures was pebbly-fine-sand-silt (E41 and E52). Most burrow structures were small and identified by the halo of oxidized sediment that surrounded the burrow (E24). Larger burrows (>1 cm diameter) were observed at seven stations in Area E (E05, E08, E15, E23, E26, E32, E46) and one in Area W (W08).

At biologically dominated stations, the number and size of the subsurface biogenic structures was consistent with equilibrium successional Stage III communities. There was also evidence of intermediate Stage II fauna, primarily tubes of *Ampelisca* spp. amphipods, at many stations. Based on the occurrence and size of subsurface biogenic structures most stations were assigned a Stage II to III designation (Tables 1 and 2).

3.5 Organism Sediment Index

The Organism Sediment Index (OSI) at most stations in both Area E and W was greater than 6, which is the lower limit of the OSI considered to represent unstressed benthic habitat for northeast estuarine and near coastal systems (Rhoads and Germano 1986). Diaz et al. (2003) demonstrated that for the OSI to be interpreted as a measure of benthic habitat condition in Chesapeake Bay, a southeast temperate estuarine system, it had to be re-scaled to reflect the latitudinal differences in habitat conditions. Interpretation of the OSI as a measure of benthic habitat conditions in Rhode Island Sound would require a similar re-scaling to reflect the differences in physical and biological dynamics between nearcoastal and estuarine systems relative to oceanic systems. In the Chesapeake Bay study, Diaz et al. (2003) found that the re-scaling lowered the breakpoint for stressed benthic habitats from 6 to 3. It is likely that re-scaling the index for the offshore dynamics in Rhode Island Sound would also have a significant effect on the breakpoint.

The benthic habitat conditions (as measured by the OSI) in Area E were relatively higher than those in Area W. The mean OSI for Area E of 8.3 (SE = 0.25) was significantly higher than that for Area W, which was 7.2 (SE = 0.40) (ANOVA, df = 1, F = 5.89, p = <0.018) (Figure 6). Within Area E, the mean OSI were significantly higher at stations classified as having biologically dominated sediment surfaces (9.8, SE = 0.27) than those with physically dominated surfaces (7.2, SE = 0.25) (ANOVA, df = 1, F = 48.71, p = <0.0001) (Figure 7). Based on the relatively high OSI values (>6), the benthic habitat at 88% (43 of 49 stations with calculated OSI values) of stations in Area E and 79% (15 of 19) in Area W appeared to be good quality with no obvious signs of stressed benthos. At the six stations in Area E (E38, E41, E42, E47, E50, and E52) and four stations in Area W (W02, W03, W06, and W15) with lower OSI values, the source of stress to the benthos appeared to be physical processes. None of the stations in Area E or W showed any evidence of stress from low dissolved oxygen in the bottom water, methane gas bubbles, or excess organic inputs.

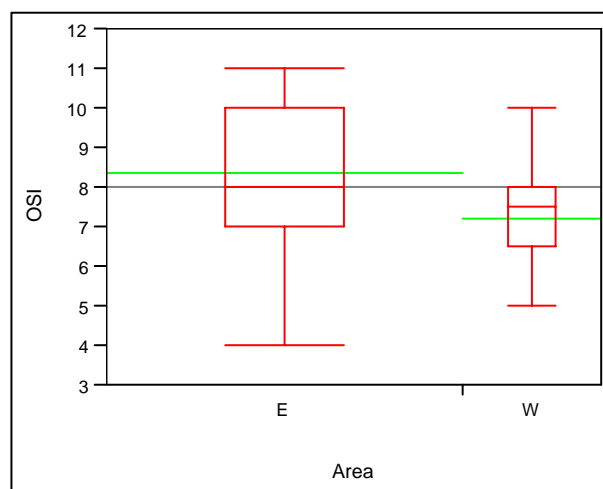


Figure 6. Box-plot of Organism Sediment Index (OSI) by Area. Box is interquartile range, tails are range, line in box is median, green line extended from box is mean, gray line is grand mean, and width of box is proportional to sample size.

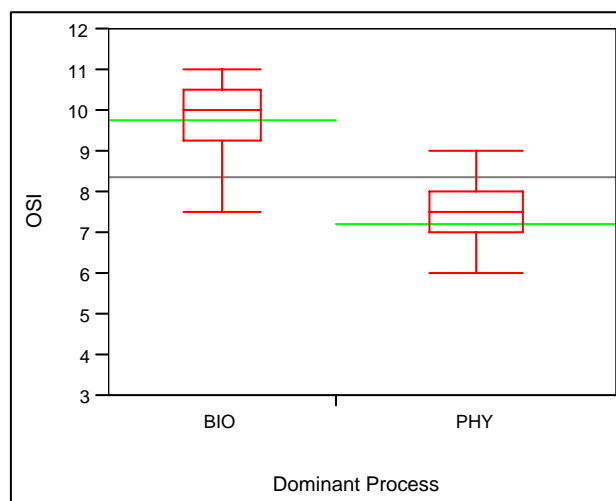


Figure 7. Box-plot of Organism Sediment Index (OSI) for Area E by Processes that Appeared to be Dominating Surface Sediments. Box is interquartile range, tails are range, line in box is median, green line extended from box is mean, gray line is grand mean, and width of box is proportional to sample size.

3.6 Comparison of Area W with Previous Surveys of Site 69B

Sediment profile camera surveys at or near Area W were conducted in June 1997, November 1999, and September 2001 (SAIC 2002). These studies sampled Site 69B, just to the east and south of Area W stations (Figure 3), and found three major sediment types fine-sand-silt-clay, mixed fine-sands, and pebbly-sand (Table 3). Most of Site 69B was very-fine-sand with the coarser sediments to the north adjacent to the coarse sediment stations in Area W. Finer sediments in Site 69B were similar to the finer sediments in Area W and did not appear to differ by more than half a Phi unit. Area W, located further to the north and west of Site 69B, had a higher proportion of coarse sediment stations. The side scan mosaic of Area W, which included Site 69B, did not indicate that Site 69B had appreciable areas of hard bottom. But the bottom at much of Site 69B did appear to be heavily disturbed with long, sweeping tracks obvious on the side scan mosaic (Figure 3).

Site 69B sediments were well reworked by benthic fauna (SAIC 2002) and appeared to be similar to Area W in sedimentary fabric and biogenic structures. Successional stage of the fauna was variable from 1997 to 2003 (Table 3). Over the time covered by the four surveys, there was a trend for pioneering Stage I stations to decline and Stage II and III to increase. The overall condition of Site 69B benthic habitats as measured by the OSI declined from 1997 to 2001, but in 2003 Area W was similar to Site 69B in 1997. A similar pattern was seen in the RPD layer depth (Table 3).

Table 3. Comparison of sediment profile image data from previous surveys at Site 69B in June 1997, November 1999, and September 2001 (SAIC 2002) just south and east of Area W sampled in August 2003 (This Report).

Sediment Types by Percentage (Number of Stations):

	Fine-Sand-Silt to Very-Fine-Sand	Fine-Sand to Med-Sand	Coarse-Sand & Coarser	Total Stations
1997	58% (11)	37 (7)	5 (1)	19
1999	96 (26)	0	4 (1)	27
2001	78 (7)	11 (1)	11 (1)	9
2003	20 (4)	45 (9)	35 (7)	20

Successional Stage:

	I	I-II	II	I-III or II-III	Total Stations
1997	59% (10)	6 (1)	29 (5)	6 (1)	17
1999	50 (13)	27 (7)	0	23 (6)	26
2001	43 (3)	0	14 (1)	43 (3)	7
2003	0	90 (18)	0	10 (2)	20

Mean Values for:

	RPD (cm)	OSI
1997	4.1	7.2
1999	2.5	6.0
2001	2.1	6.3
2003	4.3	7.2

4.0 SUMMARY

The general sedimentary characteristics of Areas E and W were similar, with large patches of coarse sediments surrounded by finer sediments found in each (Figures 4 and 5). Sediment types ranged from cobble to fine-sand with some silt at both Areas. Sediments at both Areas also had a similar sediment fabric, with most finer sediment stations dominated by biological processes.

Area E showed no signs of sediment layering. But in Area W two stations (W15 and W17) had thin layers of finer sediments that could have been related to recent sediment disturbance.

In August 2003, Area E, and to a lesser degree Area W, appeared to be dominated by biological processes with biogenic features such as feeding pits and defecation mounds common. Biogenic activity of advance successional Stage III communities was a predominant factor in structuring surface and subsurface sediments in Area E. Area W fauna appear to be advancing successional relative to previous years, based on data from Site 69B (SAIC 2002).

It did not appear that sediments at any station in Areas E or W were impacted by organic enrichment. Sediments underlying the apparent color RPD layer were light gray in color.

Overall, benthic habitat conditions at both Areas E and W appeared to be good. The only source of stress to the benthos appeared to be physical forces such as sediment instability. The apparent high quality of the benthic habitats was primarily a function of the deep dwelling infauna and their associated biogenic activities. Based on the OSI and assuming the traditional scaling in Rhodes and Germano (1986), benthic habitats in Area E may be of higher quality than those in Area W. However, a re-evaluation of the OSI scaling for application to oceanic systems would refine this interpretation.

5.0 LITERATURE CITED

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6.0 PLATES

PLATE:

- 1 Area E, stations E01 to E12, image width is 16.5 cm.
- 2 Area E, stations E13 to E24, image width is 16.5 cm.
- 3 Area E, stations E25 to E36, image width is 16.5 cm.
- 4 Area E, stations E37 to E48, image width is 16.5 cm.
- 5 Area E, stations E49 to E60, image width is 16.5 cm.

- 6 Area W, stations W01 to W12, image width is 16.5 cm.
- 7 Area W, stations W13 to W20, image width is 16.5 cm.

High resolution digital copies of the Plates can be found on the CD-ROM appendix.